Shear Production and Dissipation in a Stratified Tidal Flow

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LONG-TERM GOALS

The long term goal of this work is to understand the physics of turbulent stratified shear flows as might be found in coastal regions and estuaries where both shear and stratification are strong. It is our hypothesis that turbulence under these conditions of active generation may function in a way that is fundamentally different from weak turbulence below the thermocline (or above the bottom mixed layer) in the ocean. We anticipate that such an understanding will permit the development of accurate predictive models of turbulence dynamics for energetic coastal flows. We are also interested in how stratification of these flows affects sediment dynamics.

OBJECTIVES

This project has as its objective analyzing a relatively complete set of observations of turbulence structure and variability in Suisun Cut, a tidal channel in Northern San Francisco Bay collected in October 1999 in collaboration with Mike Gregg of the University of Washington. In this region both tides and stratification are strong: typical shears might be 0.1 s^{-1} with comparable buoyancy frequencies. These conditions typify coastal zone flows. Given these conditions, flows in Suisun Cut are found to have high turbulence Reynolds number over a wide range of flow stabilities. Current work build on our earlier work by including direct measurements of profiles of turbulence dissipation rates (Gregg) and bottom stresses using Acoustic Doppler Velocimeter (ADV) to water column ADCP derived turbulence measurements. Moreover, the data reported in Stacey et al represented the evolution of the flow over 1 tiday day during a neap tide; in the ONR supported work, we obtained nearly 2 weeks of observations spanning a complete neap-spring tidal cycle. Thus, we expect to obtain a substantially more comprehensive picture of flow behavior than was previously available.

Besides improving our empirical description of these stratified shear flows, we also plan to use this data set in conjunction with Large Eddy Simulation (LES) studies of stratified turbulence to develop new (and improved) models of stratified turbulence behavior.

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14. ABSTRACT

The long term goal of this work is to understand the physics of turbulent stratified shear flows as might be found in coastal regions and estuaries where both shear and stratification are strong. It is our hypothesis that turbulence under these conditions of active generation may function in a way that is fundamentally different from weak turbulence below the thermocline (or above the bottom mixed layer) in the ocean. We anticipate that such an understanding will permit the development of accurate predictive models of turbulence dynamics for energetic coastal flows. We are also interested in how stratification of these flows affects sediment dynamics.

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APPROACH

A comprehensive study of the tidal and spring-neap variability in turbulent mixing and stratification was carried out in October, 1999. The analysis we are carrying out examines the large-scale turbulence dynamics, including the Turbulent Kinetic Energy (TKE), Reynolds stresses, and the shear production, and how these quantities vary and interact with stratification. While not discussed in this report, the study also included the observation of turbulence microstructure by Mike Gregg of the University of Washington. We are also attempting to detail the bottom boundary layer structure including sediment flux using a set of bottom mounted ADVs.

WORK COMPLETED

Analysis of the data collected in 1999 has proceeded along two fronts:

1. Analysis of ADCP-derived turbulence data including density stratification (U.C. Berkeley)

We have analyzed the interaction of turbulence and stratification using two complementary tracks of analysis. The first is an analysis of the interaction of turbulent mixing and stratification, focused on the structure and dynamics of the benthic boundary layer. The second analysis examines the vertical and temporal variability of the turbulent kinetic energy budget, particularly the role of non-local transport. In both cases, we seek to understand how the stratifying forces in the estuary come into balance with the tidally-produced turbulence to define the levels of stratification and mixing observed.

2. Analysis of bottom turbulence and sediment dynamics (Stanford)

ADV data has been analyzed to produce time series of turbulent velocities and fluctuating sediment concentration. Our work has been focused on evaluating the accuracy of this technique and to connect its results to other measurements of the benthic boundary layer.

RESULTS

Stratified turbulence dynamics

Analysis of the estimated boundary layer depth, defined by fitting near-bottom stress profiles, indicated a strong ebb-flood asymmetry. On ebb tides, the straining of the density field by the tides produces a stabilizing buoyancy flux. During these periods, the boundary layer depth increases with increasing tidal energy and the top of the boundary layer is characterized by a gradient Richardson number of about 1/4. On the flood tides, the boundary layer depth does not vary as strongly with tidal velocity, but is instead correlated with a minimum in the tidal shear, or the location of maximum velocity. In this case, the top of the boundary layer coincides with a change in the sign of the straining buoyancy flux, with the boundary layer characterized by a destabilizing buoyancy flux. Therefore, it appears that bottom boundary layer turbulence can be driven by the destabilizing buoyancy flux created by the straining of the density field.

This analysis suggests that the TKE budget will be fundamentally different between ebb and flood tides, due to the reversal of the role of tidal straining in the turbulence budget. The second activity in the past 6 months has focused on defining the details of the TKE budget, particularly the spatial and temporal variations. From the ADCP data, we are able to calculate the shear production and the unsteadiness of TKE. Using the triple correlations of the along-beam velocities, we can estimate the non-local transport in terms of the sum of cubes of the along-beam velocities. While this estimate of the diffusive transport is an unbiased estimate, it has a large statistical uncertainty. As a result of this uncertainty, averaging beyond the 10-minute ensembles typically used for these turbulence measurements is required. Doing so, we get converged values for the shear production, unsteadiness, and the non-local transport, shown in figure 1a and 1b for the maximum ebb and flood periods.

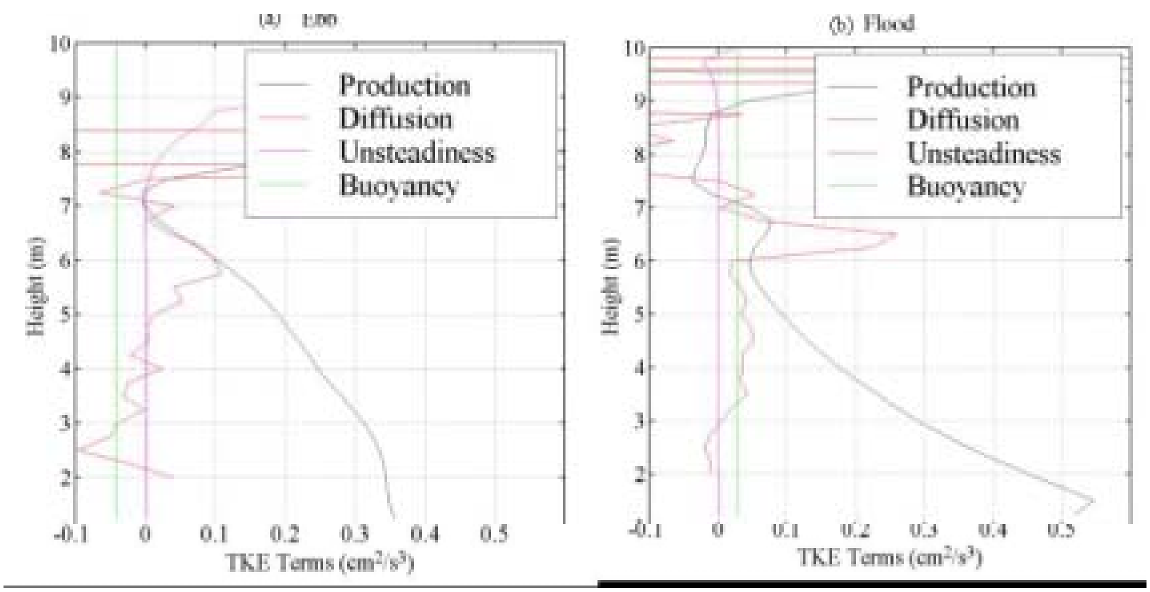

Figure 1: Comparison of terms in TKE budget for (a) Maximum ebb tides, and (b) Maximum flood tides. While local shear production is dominant throughout the bottom boundary layer, in each case, non-local production is comparable to shear production near the top of the boundary layer.

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<u>Sediment dynamics</u>

To use the ADV for SSC measurements requires empirical calibration between the amplitude of the ADV backscatter and the actual SSC. Once this calibration is obtained through comparison of mean values, the ADV yields measurements of SSC at turbulent frequencies. These concurrent ADV measurements of velocity and SSC will enable us to study how turbulence interacts with sediment at the interface between the bed and water column.

The near-bed instrument frame deployed in October 1999 carried two ADVs mounted with their measurement volumes at 0.97 m and 0.49 m above the bed. Water samples for SSC measurements were obtained from sampling ports next to the ADV sampling volumes. Unfortunately, due to a malfunction of the autosampler, calibration of the bottom ADV required a separate calibration experiment (made in October 2000). A linear fit between the SSC measurements from water samples and the backscatter amplitude of the top ADV produced significant correlationr^2=0.77 while ADV calibration with water samples from October 2000 was quite similar with r^2=0.82.Comparison of SSC values derived from the ADVs are generally the same as values derived from OBS, differing significantly for only 1% of the data pairs. The difference between the two instruments' estimates is comparable to that found between optical and acoustic backscatter sensors for sand. As shown in Figure 2A, the best agreement between the ADV-derived SSCs during neap tides is found during peak SSC loading. In fact, during most periods of larger SSC (>100 mg/L), the two SSC measurements correspond closely, with the bottom ADV SSC slightly larger, as expected. The correspondence between the two measurement continues to improve during the larger sediment loads re-suspended by spring tides (Figure 2B). However, in contrast to expected behavior, when the SSC is low, top SSC exceeds bottom SSC. During neap tides, these measurements differ by as much as a factor of 4 (Figure 2C) but only by a factor of 2 during spring tides (Figure 2D). This magnitude-dependent behavior is a direct consequence of larger gain in the calibration equation from year 2000 (0.11) as compared to that of year 1999 (0.05). The larger peak concentrations (~600 mg/L) observed during the year 2000 calibrations as compared to the peak concentrations of only ~250 mg/L during the 1999 experiment may contribute to this discrepancy.

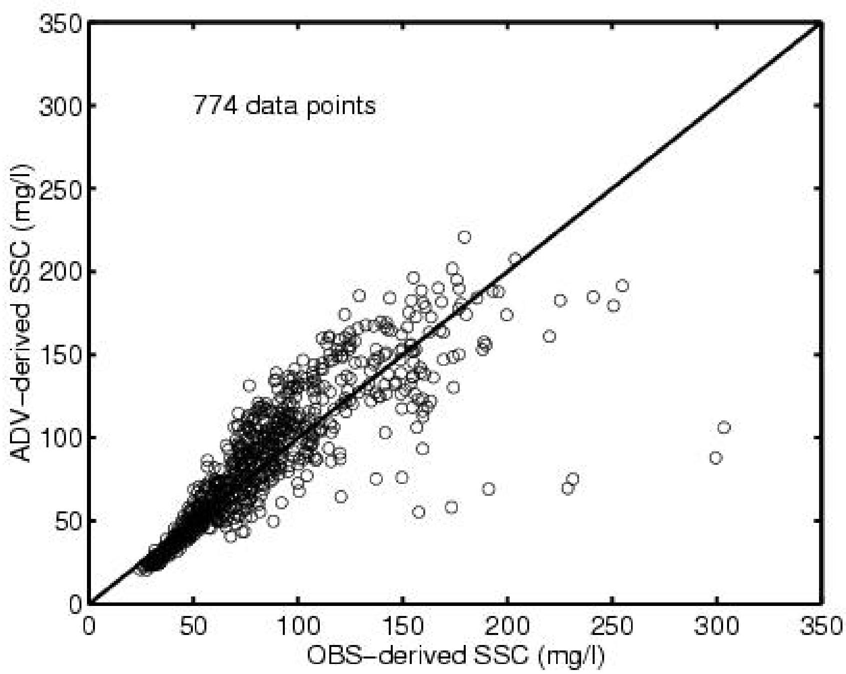

Figure 2: SSC_{ADV} vs. SSC_{OBS}, at z=0.97. Data collected 10/99 in Suisun Cutoff. This data shows a high degree of correlation between the two-different measures of sediment concentration

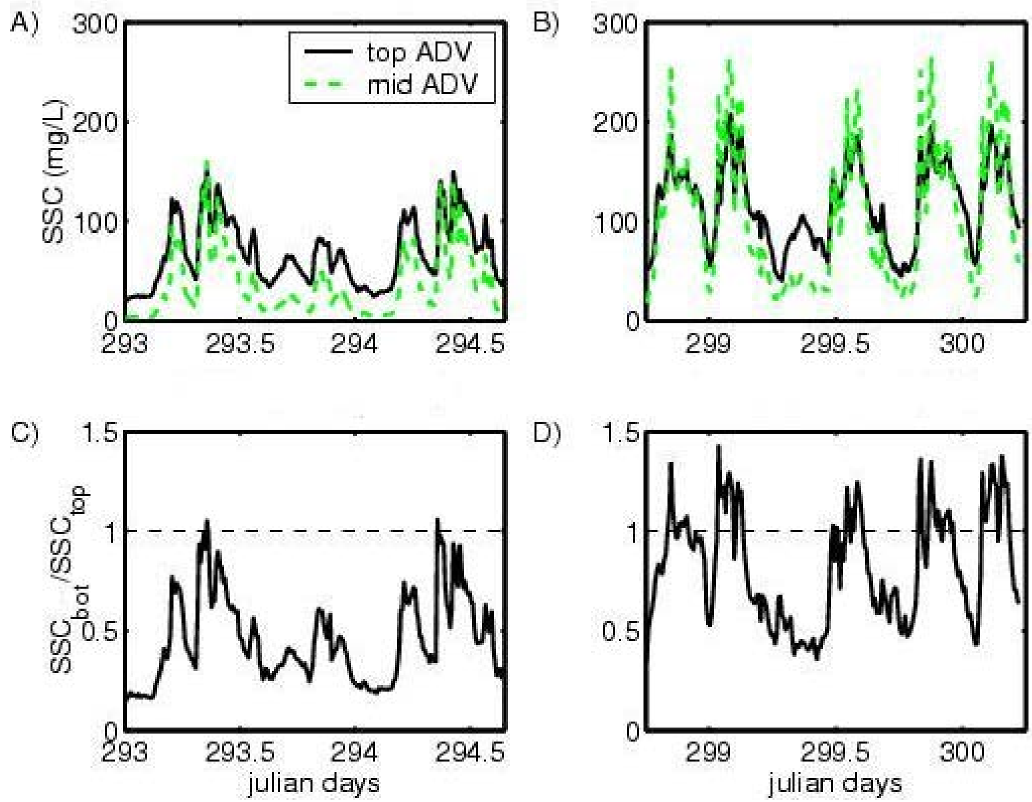

Figure 3: Time series of 10 minute mean SSC from top and bottom ADVs, 10/99, neap tide (A) and spring tide (B). Ratio of SSC from bottom ADV to SSC from top ADV, neap tide (C) and spring tide (D). This figures show that the two ADV-derived time series of SSC generally agree quite well, although there are times where higher values of SSC are seen above the bottom.

This investigation into the quality of SSC measurements generated by calibration of an ADV is an important preliminary before these measurements can be relied upon to draw further conclusions. Once these SSC measurements are validated, the simultaneous measurements of velocity and SSC at turbulent frequency may be used to examine near-bed sediment dynamics. For example, the ADV measurements of velocity and SSC can be combined to estimate the vertical turbulent sediment flux, $\langle w'c' \rangle$. This key parameter of bed flux is rarely measured directly. Instead, empirical models are commonly used to estimate erosion rates and the ensuing vertical turbulent sediment flux. This method will enable us to determine this flux in-situ, and under a wide variety of flow conditions, e.g. with waves, that might be hard to replicate in the lab.

IMPACT/APPLICATIONS

The data collected during our experiment are intended to advance our ability to predict the structure and mixing of stratified tidal flows, including sediment resuspension and erosion. In particular, the data will be made available to the coastal physical oceanography community, and will be also be used by the PIs in collaboration with colleagues at Stanford (Koseff, Ferziger, and Street) for the development of new parametrizations of stratified turbulence closures. Moreover, new methods for turbulence measurement using ADCPs and sediment fluxes using ADVs should lead to improved understanding of coastal and near-shore dynamics.

TRANSITIONS

None at this time

RELATED PROJECTS

A STUDY OF THE STRUCTURE OF NEAR COASTAL ZONE WATER COLUMN USING NUMERICAL SIMULATION (ONR - Koseff, Ferziger and Monismith) - This work is using Large Eddy Simulation to study the physics of flow influenced by stratification and by surface waves.

NEAR-SHORE HYDRODYNAMIC CONDITIONS AND CHEMICAL PLUME TRACKING (ONR Monismith) - This work supports the involvement of Dr. Derek Fong, a Research Associate in the EFML, in field experiments looking at plume dispersion and plume source in the near-shore environment. These experiments are part of the ONR Chemical Sensing in the Marine Environment Program managed by Dr. Keith Ward.

ACQUISITION OF A REMUS AUV FOR AUTONOMOUS COASTAL FLOW MAPPING (ONR- Monismith). This DURIP grant will enable us to purchase a REMUS AUV.

PUBLICATIONS

Brennan, M.L., Schoellhamer, D.H., Burau, J.R. and Monismith, S.G. 2000. "Tidal asymmetry and variability of cohesive sediment transport at a site in San Francisco Bay, California". Proceeding of the 6th International Conference on Nearshore and Estuarine Cohesive Sediment Transport Processes. (in press)